ton, picking up upon the seashore a few pebbles and discerning their lessons.

At the close of our first decennium, two speakers were brought forward to tell, respectively, what had been the aims of this University in providing for the study of science and letters. These speakers were Professor Gildersleeve and Professor Rowland. They had no preliminary conference, but each brought his discourse to a close by a return to the key-note—the key-note which had governed and should govern our personal behavior and the harmonies of our associated lives as members of the Johns Hopkins University.

Said the exponent of letters: "First and last, the scientific standard must be upheld for the university man, be he a student of letters, be he a physicist; and that standard is the absolute truth, the ultimate truth. 'Nothing imperfect is the measure of anything,' says the prince of idealists."

Said the man of science: "But for myself, I value in a scientific mind most of all that love of truth, that care in its pursuit, and that humility of mind which makes the possibility of error always present more than any other quality. This is the mind which has built up modern science to its present perfection, which has laid one stone upon the other with such care that it today offers to the world the most complete monument to human reason. This is the mind which is destined to govern the world in the future and to solve problems pertaining to politics and humanity as well as to inanimate nature.

"It is the only mind which appreciates the imperfections of the human reason and is thus careful to guard against them. It is the only mind that values the truth as it should be valued and ignores all personal feeling in its pursuit. And this is the mind the physical laboratory is built to cultivate."

These are words worthy to be recalled by the successive groups of students who come here for instruction and counsel as the years roll on. Let us sacredly cherish our inheritance.

In closing, let me call our departed brother, our dear colleague, our honored teacher, our ornament, our pride and our delight, by another nobler title. He was a servant of the Lord. If one who leads a life of purity, fidelity and integrity, and who consecrates, without self-seeking, his strength, his talents, his time, at home and at his laboratory, in health and in bodily infirmities, in youth and in maturity, to the interpretation of the laws by which the cosmos is governed, is a servant of the Lord, —then reverently and truly we may say of our departed friend he was a servant of the Lord, Maker of heaven and earth. Let me apply to him words of the Master, whom he was taught from childhood to revere. His 'eye was single' and 'his whole body was full of light.'

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*AN OUTLINE OF THE PROGRESS OF CHEMISTRY IN THE NINETEENTH CENTURY.**

CHEMISTRY is one of the youngest of the natural sciences. Its growth and development have taken place almost entirely in the past one hundred years. Nevertheless, it is well to remember that some of the foundation stones of the science were laid in the latter part of the eighteenth century. There was no such thing as a science of chemistry in the time of the ancient Greeks and Romans. Nor during the middle ages, nor previous to the year 1750 can there be said to have been any systematized chemical knowledge.

In the middle of the eighteenth century the attempt was made to explain in a general way that most striking of all ordinary

* Address delivered before the Academy of Science at St. Louis, on March 18th.

chemical changes, namely, fire or combustion. It was noticed that there are two classes of bodies, those that will burn and those that will not. The former were assumed to contain the element of fire or phlogiston. In the process of burning the phlogiston was supposed to escape into the air; the ashes or products of combustion remained behind. The act of burning was looked upon as a decomposition. Combustible bodies were all supposed to be of a compound nature, consisting of phlogiston and the products of combustion. In the act of burning these two elements separated, the phlogiston going off into the air, the products of combustion remaining behind as the ashes.

This first theory of chemistry was replaced by a better one in the year 1785 by Lavoisier, the distinguished French chemist. Last summer a bronze statue of Lavoisier was unveiled in Paris. It bears a single inscription, namely, 'The founder of Modern Chemistry.' Lavoisier found that when bodies burned the products of combustion were heavier than the original substances. A few years previous to this, in 1774, Joseph Priestley, the English clergyman, had found that when the red calx of mercury is heated oxygen gas is obtained, and that substances burn very brilliantly in this gas. Lavoisier repeated the experiments of Priestley, saw, what the latter failed to see, that burning was the union of oxygen with the burning substance and that combustion was a chemical combination and not a decomposition. 'There is no such thing as phlogiston, the element of fire,' said Lavoisier; and from this time on all substances that could not be resolved into simpler substances weighing less than the original substances were called elements.

Thus began a new era for chemistry, a quantitative era, in the year 1785. From now on the balance became the chief instrument of chemical investigation. Such in brief was the condition of chemistry one hundred years ago. The ideas of Lavoisier had, at the opening of the last century, come to be very generally accepted, but very little was known beyond these. Oxygen was the chief element and the oxides the chief compounds or, as Berzelius said: 'Oxygen was the center point about which chemistry revolved.' The knowledge of the composition of other substances was very imperfect. It was not even known at that time that substances do have a fixed composition; indeed the fundamental laws of chemical action were still all undiscovered. Almost nothing was known of the composition of substances of vegetable or animal origin, that great and important class of bodies that we now know as organic substances. A century ago it was not known that alcohol contained oxygen; this fact was found out in the year 1809. There were no laws and principles, no generalizations; chemistry consisted of purely descriptive matter, and that was often very imperfect. In organic chemistry was largely mineralogy, organic chemistry was chiefly botany.

Limited as chemical knowledge was when the nineteenth century opened, there were, however, certain men at work, who had adopted the quantitative methods of Lavoisier, and who soon made important discoveries. First of all Proust, in 1801, announced that every chemical compound has a fixed and definite composition, that when substances unite chemically they do so in definite ratios by weight. This statement of Proust's was not allowed to go unchallenged. C. L. Berthollet maintained that compounds have a variable composition, and that if there are any that do appear to have a fixed composition it is an exception and not the rule. For eight years the controversy was carried on between these men. Proust finally came out victorious. More and more analyses of compounds were made,

until it was clearly established that every distinct substance has a fixed and unalterable composition. The second great law of combination was discovered in 1804 by John Dalton, and it is commonly called the law of multiple proportions. To explain these laws of combination, Dalton introduced the atomic theory into chemistry, and from now on the great problem was to determine the relative weights of the atoms. When the history of chemistry in the nineteenth century comes to be written, it will be largely the history of the atomic theory, and for more than sixty years the two great problems to which the most eminent men gave their attention were the determination of the atomic weights and of the arrangement of the atoms in compounds. It would be a long story to trace out step by step how these problems were solved. The men who did most in this direction were Berzelius, Dumas, Liebig, Gerhardt and Laurent, Cannizzaro and Kekulé. As a result of their work, it began to be generally recognized, about 1865, that these two problems had been satisfactorily solved, and from that time on there has been no question as to the reasoning employed in fixing upon a number to represent the atomic weight of an element, or to determine the way in which the atoms are linked together in a compound.

Side by side with this development of chemical theory has gone the discovery of new elements and compounds. Instead of the thirty elements or simple substances known at the beginning of the last century, we now have seventy-eight. Instead of a few scores of distinct compounds of definite composition, we now have thousands of these substances. To-day there are known 75,000 compounds of carbon alone. In the years 1859 and 1860 Bunsen and Kirchoff devised the spectroscope, and it has become, next to the balance, the most important instrument of chemical investigation. By means of it the elements rubidium, cesium, thallium, indium, gallium, scandium and helium have been discovered.

THE PERIODIC LAW.

Soon after the atomic weights had been determined satisfactorily, a very remarkable relationship was discovered by Lothar Meyer and Mendelejeff to exist between the atomic weights and the properties of the elements. It was found that when the elements were arranged in the order of increasing atomic weights, beginning with the lowest and going up regularly to the highest, there was a periodic variation in the properties of the elements. For example, it was noticed that the 8th element resembled the first, the 9th was analogous to the 2d, and so on. Mendelejeff expressed this fact in the following way: "The properties of the elements," he said, "are a periodic function of their atomic weights." By means of this law Mendelejeff was able to foretell the existence of new elements and to predict their chemical and physical properties. When the table of elements was first arranged it was incomplete, there were blank spaces. Mendelejeff predicted that elements would be found that would fill these spaces, and from the properties of the adjoining elements he foretold the properties of the unknown elements. In this way he predicted the properties of an element that would resemble boron, another that would be analogous to aluminum, and a third that would be closely related to silicon. These predictions have all been fulfilled. In 1879 Nilson discovered scandium and found that it had all of the properties of the unknown element that resembled boron, in 1875 Boisbaudran discovered gallium; it was the element resembling aluminum, and in 1885 Winkler discovered germanium; its properties were almost identical with those that had been predicted for the element resembling silicon.

NEW ELEMENTS FOUND IN AIR.

In the last few years it has been found that ordinary air contains some elements, the existence of which had not even been suspected. For nearly three-quarters of a century it was supposed that we knew all about the composition of the air, but in 1892 Lord Rayleigh found that a globe filled with atmospheric nitrogen weighed more than the same globe filled with nitrogen made from chemical compounds containing nitrogen, and this observation followed up led to the discovery of argon, an inert gas, present to the extent of about one per cent. in the air. Then efforts were made to find argon in mineral substances; certain minerals that were supposed to give off nitrogen on heating were heated in vacuous vessels and thus helium was discovered. Recently Professor Ramsey has found two other inert gases in air besides argon; he obtains them by the fractional evaporation of liquid air, and he has named them neon and kripton. Quite recently it has been claimed that the mineral pitch blende contains the elements radium, polonium and actinium, and that these elements emit rays that are capable of producing skiagraphic images on sensitive plates, and of discharging electrified bodies.

PROGRESS IN INDUSTRIAL CHEMISTRY.

Hand in hand with the development of scientific chemistry and the discovery of new compounds has gone the improvement of manufacturing processes and the methods of industrial chemistry. At the beginning of the last century potash was the chief alkali, and this was obtained from wood ashes. Leblanc invented a method of obtaining soda from salt, and for many years this was the only way of getting alkali on the large scale. Now this method has been almost entirely replaced by the Solvay or ammonia-soda process, and it is very probable that before many years this in turn will be replaced by the electrolytic process of obtaining alkali from salt solutions. There is a constant evolution of new methods in chemical industry, the older processes have to give way to more economic and perfect methods. For more than one hundred years, all the sulphuric acid that is used has been made in lead chambers, and one improvement after the other was added to this process until it was brought to a high state of perfection; but now, with the opening of the new century, the sulphuric acid manufacturers are pulling down their lead chambers. A new and better method of making the acid has been devised. Sulphur dioxide and air are led over finely divided platinum and the resulting sulphur trioxide is conducted into water. It has long been known that sulphuric acid can be made in this way on the small scale in the laboratory, but it is only recently that the principle has been adapted to the commercial preparation of the acid. Heretofore the difficulty has been that the contact substance, the finely divided platinum, soon lost its activity. Now it has been found that this can be overcome by carefully purifying the gases before they come in contact with the platinum, and that, by keeping the temperature of the interacting gases below the point of decomposition of the sulphur trioxide, the action can be carried on indefinitely and on the commercial scale. The resulting sulphur trioxide is led into water and sulphuric acid of any degree of concentration obtained.

Other important changes in industrial chemistry have been brought about by the application of electricity to the preparation of chemical elements and compounds. Places like Niagara Falls that have abundant water power for the production of electric currents are rapidly becoming the seats of important chemical industries. The electric current is at present used chiefly in two ways in inorganic chemistry. First

it is used for the production of very high temperatures in the electric furnace. In simple form the electric furnace consists of a box made of fire bricks in which the carbon poles of an electric arc light are placed. Under the influence of the high temperatures produced between the carbon pencils nearly all metal oxides are reduced by carbon. Aluminium oxide is reduced in this way at Niagara Falls, and aluminium bronze, an alloy of aluminium and copper, is made. Sand is reduced in the same way, and the element silicon unites with the excess of carbon and forms the compound carborundum, an exceedingly hard substance which is used so extensively as a substitute for emery. Artificial graphite and phosphorus are also made in the electric furnace and the carbides of a large number of metals have been prepared. Of these carbides calcium carbide has become of commercial importance, as it is used extensively for making acetylene.

The other way in which the electric current is utilized is for the electrolysis of liquids, either solutions of substances in water or fused substances. At Niagara metallic sodium is now made by the electrolysis of fused caustic soda. One of the uses of the metallic sodium is to prepare sodium peroxide, the new bleaching agent, for which purpose the metal is burnt in dry air. Metallic aluminium is obtained by the electrolysis of aluminium oxide in a fused bath of cryolite. Caustic soda and chlorine are made by the electrolysis of salt solutions, and potassium chlorate by the electrolysis of potassium chloride solution. The electric current is also used in refining certain metals, for which purpose sheets of the crude metal are suspended at one pole in a bath of the metal salt and the pure metal deposited at the other pole.

During the past century great progress has been made in the methods of extracting the metals from their ores. Not only has this been true of iron, but of all the useful metals. As an example, it is only necessary to call attention to the cyanide process of extracting gold and silver. Gold and silver ores which are so poor that it was unprofitable to work them in previous years are now successfully treated with a solution of potassium cyanide, which has the power, in the presence of air, of dissolving the noble metals. It is this method which has largely contributed to the increased production of gold in recent years. Side by side with this improvement of metallurgical processes has gone the utilization of by-products. Not only is blast-furnace slag used in making Portland cement, but other slags, such as those obtained in the basic steel process and which contain phosphoric acid, are used as fertilizers. The sulphur dioxide formed by roasting lead and zinc ores is no longer allowed to escape into the air, but is converted into sulphuric acid.

PROGRESS IN ORGANIC CHEMISTRY.

But undoubtedly the most rapid strides in the development of chemistry have been made in the past century in that department known as organic chemistry. One hundred years ago our knowledge of the compounds occurring in the organs of plants and animals was very meager indeed. A few organic substances had been isolated, but their composition was very imperfectly known, as the methods of analysis were very crude. Liebig in 1830 improved the method of analyzing these compounds and thus laid the foundation of organic chemistry.

A century ago it was generally believed that organic compounds could not possibly be made artificially by synthesis in the laboratory, as was the case with mineral compounds. It was thought that a peculiar vital force in some way intervened in their production in the organs of plants and

animals, and that we could never expect to prepare them in the laboratory. But this idea soon had to be abandoned, for in 1828 Wöhler succeeded in building up urea from simple inorganic substances, and thus the first synthesis of an organic substance was effected. This was soon followed by that of acetic acid by Kolbe, and then year after year an ever larger and larger number of substances was added to the list of synthetic compounds. It would take too long to enumerate all the compounds that have been made artificially in the laboratory. It is enough to say that the hydrocarbons of petroleum, common alcohol, wood alcohol, fusel oil, the ethers, the etheral and essential oils, the fatty acids, glycerine, grape sugar and fruit sugar, coloring matters and dye stuffs like indigo and turkey red, aromatic substances like oil of bitter almonds, vanilline and coumarine and many others, have been made.

One hundred years ago it was generally believed to be impossible for two substances of entirely different properties to have the same composition. When Liebig in 1823 found that Wöhler had analyzed silver cyanate and stated the percentage composition, he saw that it was identical with the percentage composition of silver fulminate as found by himself. He at once wrote to Wöhler and told him that he must have made a mistake. Silver cyanate and silver fulminate were very different substances, he said; they could not possibly have the same composition. Wöhler repeated his analyses and found that they were correct. Liebig again analyzed silver fulminate and found that his figures also were correct. Both substances had the same percentage composition. A few years after, Berzelius showed that racemic and tartaric acids have the same composition, but different properties, and from this time on substances of this kind have been called isomeric. This phenomenon of isomerism, so rare at one time, is now very common. We have, for example, 55 substances having the formula $C_9H_{10}O_3$, all having the same elements in the same proportions, or the same kind of atoms and the same number of atoms of each kind. To explain isomerism it was necessary to assume that in these different bodies the atoms are differently arranged or grouped. Thus there came into chemistry the idea of structure or constitution, and by this term is meant the way in which the atoms are united to form the smallest particles of compounds. By studying the methods of formation and of decomposition of compounds it has been found possible to draw conclusions as to which atoms are more closely associated with one another. In the year 1865 the methods of determining the constitution of substances had been brought to a high state of development as the result of the work of Professor Kekulé in Bonn. Kekulé proved experimentally that in a compound each atom is not united directly with all the other atoms, but that certain atoms act like links in a chain and hold different atoms together to form definite structures.

The immediate effect of this theory was that it led to a great deal of work, the object of which was to determine the way in which the atoms are linked in different substances. When once this structure had been determined, it was easy to see how the compound might be built up from simpler substances. The outcome was that hundreds of substances were made synthetically, and in the attempt to make artificially the valuable and useful substances, very often new ones were discovered that in turn were found to possess valuable properties. For instance, after determining the constitution of atropine, Ladenburg, in making it synthetically, succeeded in making several modified atropines, such as homoatropine, which also have valuable properties. Professor Fischer attempted to unravel the

structure of grape sugar and to make it synthetically; he succeeded in this, but, in addition, he has made 20 other sugars that had never been known before.

As work went on in organic chemistry and the methods of working with these substances were improved, and the means of distinguishing between them became more refined, it was found that there were even finer kinds of isomerism than had at first been observed. It is possible to have two or more substances of identical composition and of exactly the same chemical behavior, but differing from one another in only a very slight way. For example one compound will rotate the plane of polarized light a certain number of degrees to the right while the other will rotate the plane the same number of degrees, but to the left. In short there are right and left handed compounds. This physical isomerism, as it is called, can only be explained by assuming a different arrangement of the atoms in space. Since 1888 a great deal of work has been done in the development of the theories of space chemistry or stereochemistry. We are in a position now not only to determine how the atoms are linked to one another but also how they are actually grouped in space. Stereochemistry is the most attractive field of research in organic chemistry to-day. Prominent among the men who have contributed to this department of chemistry are Van't Hoff, Wislicenus, Baeyer and Emil Fischer.

PROGRESS IN PHYSICAL CHEMISTRY.

During the past fifteen years the borderland between chemistry and physics has been very successfully cultivated, and a new department of chemistry has resulted. This is the department known as physical chemistry, and it deals with such subjects as thermo- and electrochemistry, with chemical statics and chemical dynamics and with the laws of solution and electrolytic dissociation. A great deal of progress has been made in all these directions. It is especially the new theories of solution and of electrolytic dissociation that have most profoundly changed our ways of looking at chemical action. We now regard a substance in solution as in a condition analogous to the gaseous state. Like a gas, the dissolved substance exerts pressure, and this pressure, which is known as osmotic pressure, obeys the same laws that gas pressure does. One great practical benefit that has resulted from the laws of solution is that it is no longer necessary to convert a substance into a gas in order to find its molecular weight; it is only necessary to dissolve it in some solvent, and from the changes which it produces in the freezing point or boiling point or vapor tension of the solvent to calculate the molecular weight.

The theory of electrolytic dissociation has greatly modified our ways of interpreting the ordinary reactions of analytical chemistry. We now hold that in all dilute solutions of acids, bases and salts, in short the compounds of inorganic chemistry, we have no longer the unchanged substances, but their positive and negative ions. In the act of dissolving in water the acids, bases and salts are more or less completely split into their ions, and the chemical changes that take place in these solutions are reactions between these ions. A great many facts of analytical chemistry, of electrolysis and such empirical laws as the law of thermoneutrality of salt solutions and of the constant heat of neutralization of acids and bases, heretofore inexplicable, have now received a rational and natural explanation by means of this theory of electrolytic dissociation.

EDWARD H. KEISER.

CAMPANUS.

MANY of the early editions of the 'Elements' of Euclid, among them the *editio prin-*